UNCLASSIFIED

AD NUMBER
AD474861
LIMITATION CHANGES

TO:

Approved for public release; distribution is unlimited.

FROM:

Distribution authorized to U.S. Gov't. agencies and their contractors; Critical Technology; DEC 1965. Other requests shall be referred to Arnold Engineering Development Center, Arnold AF Station, TN. This document contains export-controlled technical data.

AUTHORITY

AEDC 29 Dec 1971

THIS PAGE IS UNCLASSIFIED

DYNAMIC STABILITY TESTS ON A 1/5-SCALE MODEL OF THE BIG Q AIR-TO-AIR MISSILE AT MACH NUMBERS FROM 1.5 TO 4

G. E. Burt

ARO, Inc.

December 1965

VON KÁRMÁN GAS DYNAMICS FACILITY
ARNOLD ENGINEERING DEVELOPMENT CENTER
AIR FORCE SYSTEMS COMMAND
ARNOLD AIR FORCE STATION, TENNESSEE

NOTICES

DYNAMIC STABILITY TESTS ON A 1/5-SCALE MODEL OF THE BIG Q AIR-TO-AIR MISSILE AT MACH NUMBERS FROM 1.5 TO 4

G. E. Burt

ARO, Inc.

FOREWORD

The work reported herein was done at the request of the Air Force Weapons Laboratory (AFWL), Research and Technology Division (RTD), Air Force Systems Command (AFSC) under Program Element 62405064, Project 5797, Task 579712.

The results of the tests presented were obtained by ARO, Inc. (a subsidiary of Sverdrup and Parcel, Inc.), contract operator of the Arnold Engineering Development Center (AEDC), AFSC, Arnold Air Force Station, Tennessee, under Contract AF40(600)-1200. The tests were conducted from September 13 to 15, 1965 under ARO Project No. VA0608, and the manuscript was submitted for publication on November 9, 1965.

This technical report has been reviewed and is approved.

Darreld K. Calkins
Major, USAF
AF Representative, VKF
DCS/Test

Jean A. Jack
Colonel, USAF
DCS/Test

ABSTRACT

Tests were conducted in the 40-in. supersonic tunnel of the von Kármán Gas Dynamics Facility to determine the dynamic stability characteristics of a 1/5-scale model of the Big Q air-to-air missile. Data were obtained at Mach numbers from 1.49 to 3.99 at the model trim angle of attack and at plus and minus 1 to 2 deg from trim at a near constant Reynolds number of 8×10^6, based on model length. The effects of Mach number and canard angle on the damping-in-pitch derivatives and effective slope of the pitching-moment curve at the trim angle of attack are presented.

CONTENTS

ILLUSTRATIONS

NOMENCLATURE

A	Reference area (model body cross-sectional area), ft^2
C_m	Pitching-moment coefficient, pitching moment/$q_\infty Ad$
C_{m_q}	$\partial C_m / \partial (qd/2V_\infty)$ ⎫ Damping-in-pitch derivatives, 1/rad
$C_{m_{\dot{\alpha}}}$	$\partial C_m / \partial (\dot{\alpha} d/2V_\infty)$ ⎭
C_{m_α}	Slope of the pitching-moment curve $\left(\partial C_m / \partial \alpha\right)_{\alpha = 0}$, 1/rad
C_{m_θ}	Effective slope of the pitching-moment curve, 1/rad
Cy_R	Cycles to damp to a given ratio R, cycles
d	Reference length (model diameter), ft
f	Frequency of oscillation, cycles/sec
I	Model mass moment of inertia about the pivot axis, slug-ft^2
ℓ	Model length, in.
M_θ	Angular restoring-moment parameter, ft-lb/rad
$M_{\dot{\theta}}$	Angular viscous-damping-moment parameter, ft-lb-sec/rad
M'_θ	Aerodynamic angular restoring-moment parameter, ft-lb/rad
$M'_{\dot{\theta}}$	Aerodynamic angular viscous-damping-moment parameter, ft-lb-sec/rad
M_∞	Free-stream Mach number
q	Pitching velocity, rad/sec
q_∞	Free-stream dynamic pressure, lb/ft^2
R	Ratio of amplitude of a damped oscillation after a given number of cycles to the initial amplitude
Re_ℓ	Reynolds number based on model length
t	Time, sec

V_∞	Free-stream velocity, ft/sec
x_{cg}	Distance from model nose to pivot axis, in.
α	Angle of attack, deg
$\dot{\alpha}$	Time rate of change of angle of attack, rad/sec
α_t	Trim angle of attack, deg
δ	Canard deflection angle, deg
θ	Angular displacement, rad or deg
$\dot{\theta}$	Angular velocity, rad/sec
$\ddot{\theta}$	Angular acceleration, rad/sec^2
ϕ	Model angular coordinate, deg
ω	Angular frequency, rad/sec
$\dfrac{\omega d}{2V_\infty}$	Reduced frequency parameter, rad

SUBSCRIPTS

o	Maximum conditions
v	Vacuum conditions
w	Wind-on conditions

SECTION I
INTRODUCTION

Tests were conducted on a 1/5-scale model of the Big Q air-to-air missile to determine its dynamic stability characteristics at Mach numbers ranging from 1.5 to 4 and canard angles of 0, 5, 10, and 15 deg. Static stability tests were conducted on this model in June 1965 over essentially the same range of test conditions and with the same canard angles (Ref. 1). The model was tested at a near constant Reynolds number of 8×10^6, based on model length, at its trim angle of attack (α_t) and ± 1 to ± 2 deg from α_t.

The tests, as outlined in Table I, were conducted using a small amplitude (± 3 deg), free oscillation, cross-flexure pivot balance. Data obtained at all Mach numbers and canard angles at the model trim angle of attack are presented.

SECTION II
APPARATUS

2.1 WIND TUNNEL

The 40-in. supersonic tunnel (Gas Dynamic Wind Tunnel, Supersonic (A)) is a continuous, closed-circuit, variable density wind tunnel with an automatically driven flexible plate-type nozzle and a 40- by 40-in. test section. The tunnel operates at Mach numbers from 1.5 to 6 at maximum stagnation pressures from 29 to 200 psia, respectively, and stagnation temperatures up to 300°F ($M_\infty = 6$). Minimum operating pressures are about one-tenth of the maximum at each Mach number. A description of the tunnel and airflow calibration information may be found in Ref. 2.

2.2 MODEL

Details of the Big Q model are shown in Fig. 1. The model (Fig. 2), supplied by AFWL, has a 9-deg half-angle, blunted conical nose with cruciform canards and a cylindrical afterbody with cruciform fins in line with the canards. The canards at $\phi = 90$ and 270 deg could be pitched at angles from 0 to 15 deg. The canards at $\phi' = 0$ and 180 deg were fixed at zero inclination with the model centerline. A spacer was provided to locate the balance pivot axis 12.00 in. aft of the model nose ($x_{cg}/\ell = =0.522$), and ballast was added to locate the model center of gravity exactly at the balance pivot.

2.3 STING-BALANCE SYSTEM

The dynamic stability balance (Fig. 3) is a one-degree-of-freedom, free oscillation, sting-supported system incorporating a cross flexure

as the pivot. The balance was designed for an initial displacement amplitude of about 3 deg; however, the model geometry limited the displacement to slightly above 2 deg. The model could be locked remotely by means of the locking device shown in Fig. 3 which was actuated by a solenoid located in the aft portion of the sting. The model was locked when the pin on the locking device engaged a hole in the model bulkhead (Fig. 4).

Figure 4 shows the oscillating air system which was used to displace the model. The driving force was obtained from a high pressure air supply which could be adjusted to the pressure level necessary to overcome the damping moment on the model by means of a pressure regulator. The model was oscillated by bursts of air alternately emitted from two jets by an oscillating servo valve at a frequency which could be varied remotely by means of a low frequency oscillator. The driving force could be stopped abruptly by a remotely operated solenoid valve.

SECTION III
PROCEDURE

The equation of motion for a free oscillation, one-degree-of-freedom system may be expressed as

$$I\ddot{\theta} - M_{\dot{\theta}}\dot{\theta} - M_{\theta}\theta = 0$$

The method for computing the dimensionless damping-in-pitch derivatives is indicated by the following expressions:

$$\theta = \theta_o e^{(M_{\dot{\theta}}/2I)t} \sin \sqrt{-M_{\theta}/I}\ t$$

$$M_{\dot{\theta}} = \frac{2I\ f\ \ell n\ R}{Cy_R}$$

$$M'_{\dot{\theta}} = M_{\dot{\theta}_w} - M_{\dot{\theta}_v}\ (\omega_v/\omega_w)$$

$$C_{m_q} + C_{m_{\dot{\alpha}}} = M'_{\dot{\theta}}(2V_{\infty}/q_{\infty}\ A\ d^2)$$

The expression for obtaining the aerodynamic viscous-damping-moment parameter ($M'_{\dot{\theta}}$) is based on the premise that the structural damping of a cross-flexure pivot varies inversely with the frequency of oscillation (Ref. 3).

The change in model oscillation frequency from the wind-off to the wind-on condition may be used to obtain the effective slope of the

pitching-moment curve by the following expressions:

$$M_\theta = -I\omega^2$$

$$M_\theta' = M_{\theta_w} - M_{\theta_v}$$

$$M_\theta' = -I(\omega_w^2 - \omega_v^2)$$

$$C_{m_\theta} = M_\theta' / q_\infty A d$$

The test procedure for obtaining the data was to adjust the oscillator and pressure regulator (Fig. 4) until the air jets were forcing the model at its undamped natural frequency and required amplitude. The solenoid valve was then closed, which allowed the model to oscillate freely. The oscillatory motion of the model, monitored by a strain-gage bridge on the outside flexure (Fig. 3), was recorded by a direct writing oscillograph. A signal to indicate the exact time at which the solenoid was closed was also recorded on the oscillograph.

SECTION IV
PRECISION OF MEASUREMENTS

The balance was calibrated during bench tests before and after testing. The calibrations were obtained by use of known moments and displacements which were accurate within ±1 percent of their maximum value.

Both the damping-in-pitch derivatives ($C_{m_q} + C_{m_{\dot\alpha}}$) and the effective slope of the pitching-moment curve (C_{m_θ}) are affected by the uncertainties in determining the model moment of inertia (I), angular frequency of oscillation (ω), and tunnel free-stream dynamic pressure (q_∞). The damping derivatives are also affected by uncertainties in the amplitude ratio (R), the number of cycles to damp to this ratio (C_{y_R}), and the free-stream velocity (V_∞).

As a result of the above sources of error, the estimated maximum uncertainties in $C_{m_q} + C_{m_{\dot\alpha}}$ amd C_{m_θ} are given in Fig. 5.

SECTION V
RESULTS AND DISCUSSION

Figure 6 shows the effect of canard deflection angle (δ) on the damping-in-pitch derivatives ($C_{m_q} + C_{m_{\dot{\alpha}}}$) and effective slope of the pitching-moment curve (C_{m_θ}) at the model trim angle of attack at Mach numbers of 1.49, 1.99, 2.48, 2.99, and 3.99. Increasing δ has no appreciable effect on $C_{m_q} + C_{m_{\dot{\alpha}}}$ but increases C_{m_θ} except for Mach 3.99, where C_{m_θ} is practically invarient.

Data from Fig. 6 have been plotted in Fig. 7 to show the influence of Mach number for a given canard deflection angle. The results show that the damping derivatives decrease as Mach number increases for all canard deflection angles, and the model is dynamically stable at all conditions. For all canard deflection angles other than zero the model is statically stable and the effective slope of the pitching-moment curve decreases, to make the model less stable, as Mach number is increased. Increasing Mach number increases the model's static stability for zero canard deflection and shows the model to be unstable at Mach 1.5 and 2.

The pitching-moment curve slope data (C_{m_α}), from Ref. 1, for zero canard deflection are shown in Fig. 7 and are not in good agreement with the present data. In fact, the present data indicate that a slope reversal occurs in the pitching-moment curves between angles of attack of ±1 deg at M_∞ = 1.5 and 2.

The data from the static force tests were obtained at $-1 \geqq \alpha \geqq 2$ and show some nonlinearities in the pitching moment near zero angle of attack. The pitching-moment curve slopes (C_{m_θ}) obtained in the dynamic stability tests correspond to the effective moment for an amplitude range of ±1.5 deg which encompasses the region of the nonlinearity. Although not presented here, static-moment data from the dynamic stability tests show that the nonlinearity in the pitching moment decreases with increased Mach number, and thus it would be expected that the data from Ref. 1 would be in better agreement with the present results at the higher Mach numbers.

It is believed, however, that if the static-force data were obtained over a smaller angle-of-attack range near α = 0 the results would be in better agreement with the present data.

Figure 8 shows the model trim angle-of-attack (α_t) variation with Mach number for canard deflection angles of 5, 10, and 15 deg and data from Ref. 1. The agreement is believed to be within the accuracy of the two balance systems.

REFERENCES

1. Uselton, J. C. "Force Tests on a Model of the Big Q Air-to-Air Missile at Mach Numbers from 1.5 to 4." AEDC-TR-65-119, (AD 464953), June 1965.

2. Test Facilities Handbook (5th Edition). "von Kármán Gas Dynamics Facility, Vol. 4." Arnold Engineering Development Center, July 1963.

3. Welsh, C. J. and Ward, L. K. "Structural Damping in Dynamic Stability Testing." AEDC-TR-59-5 (AD 208776), February 1959.
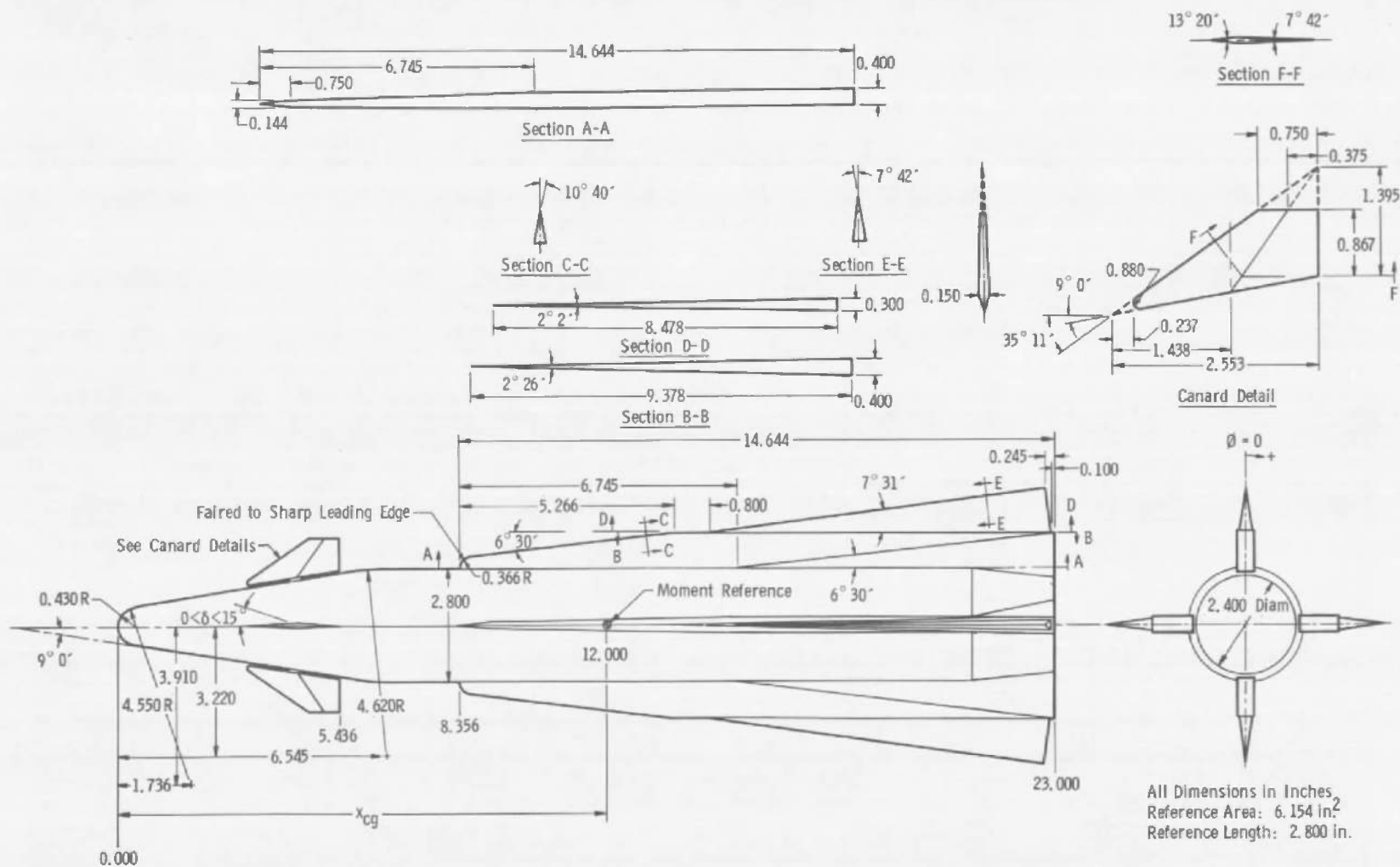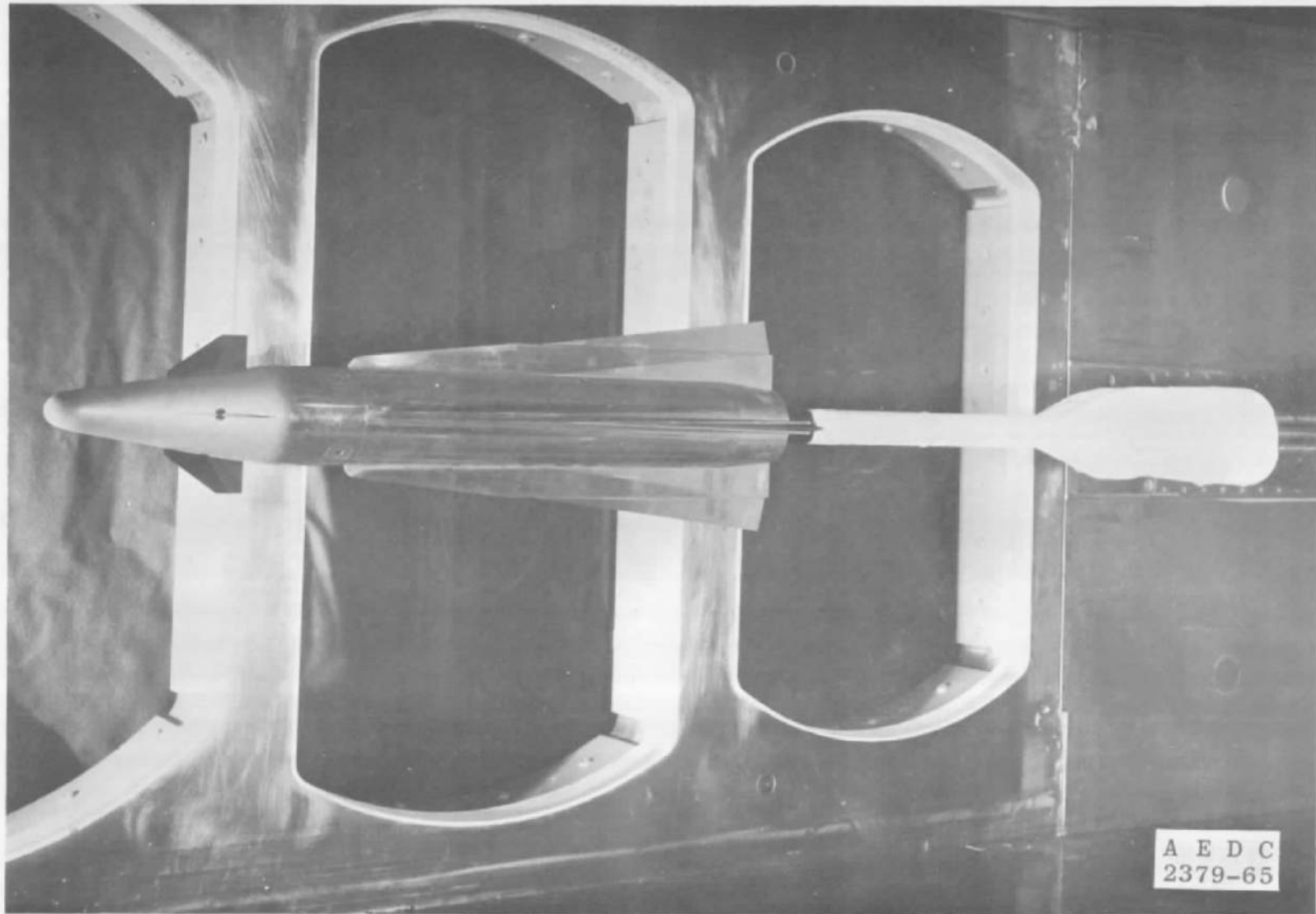
Fig. 1 Model Details
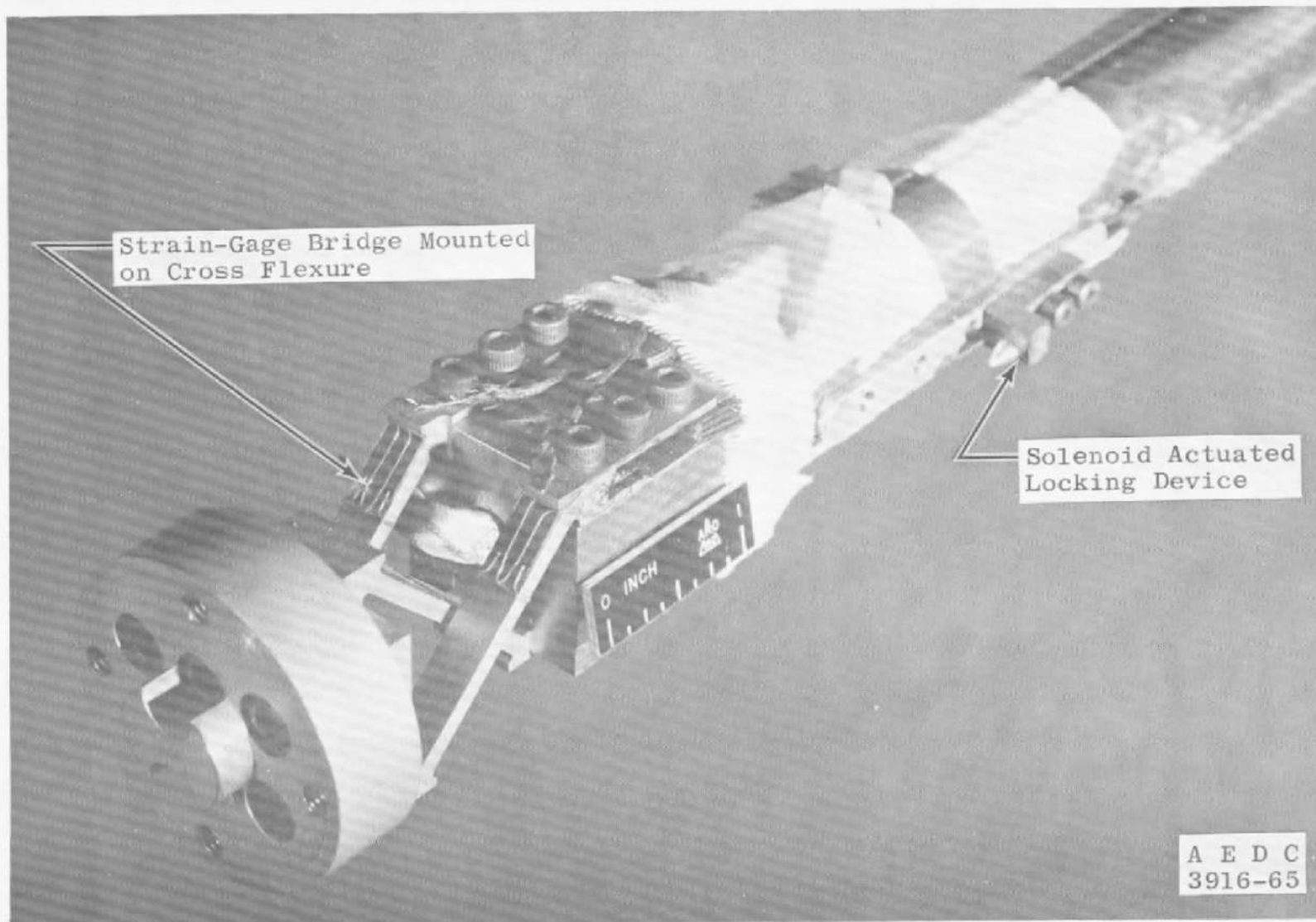
Fig. 2 Photograph of Model Installed in Tunnel A

Strain-Gage Bridge Mounted
on Cross Flexure

Solenoid Actuated
Locking Device

O INCH

AEDC
3916-65

Fig. 3 Photograph of Balance

Strain-Gage Bridge

Cross Flexures

Model
Bulkhead

Locking Device

Jets

Locking
Wire

Spacer

Tunnel Wall

Vented to Tunnel
Static Pressure

Solenoid Valve

To 28-v DC Power Supply
Oscillating Servo Valve

To Oscillator
and Amplifier
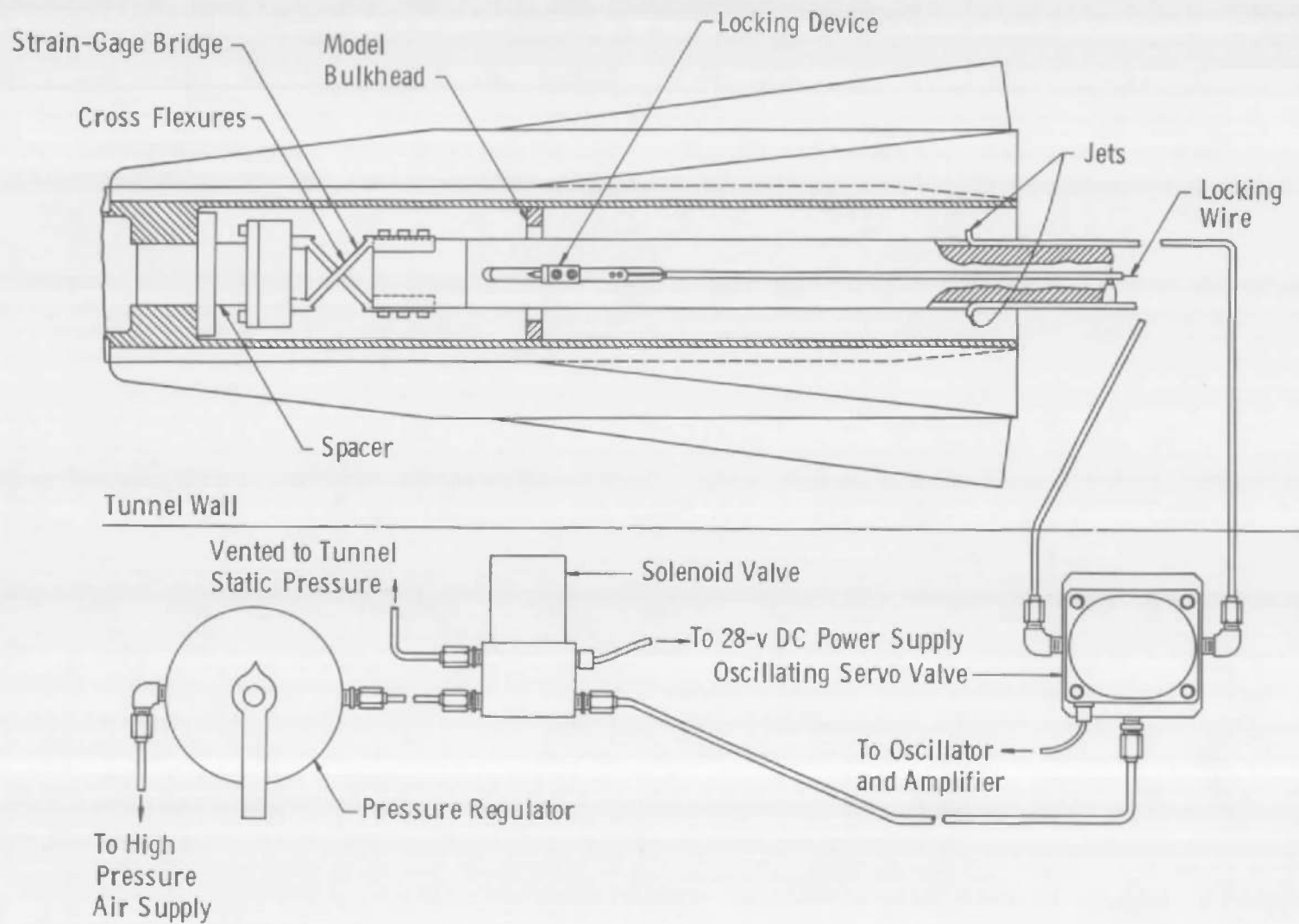
Pressure Regulator

To High
Pressure
Air Supply

Fig. 4 Model Displacement System

Fig. 5 Uncertainty in the Damping-in-Pitch Derivatives and Effective Slope
of the Pitching-Moment Curve

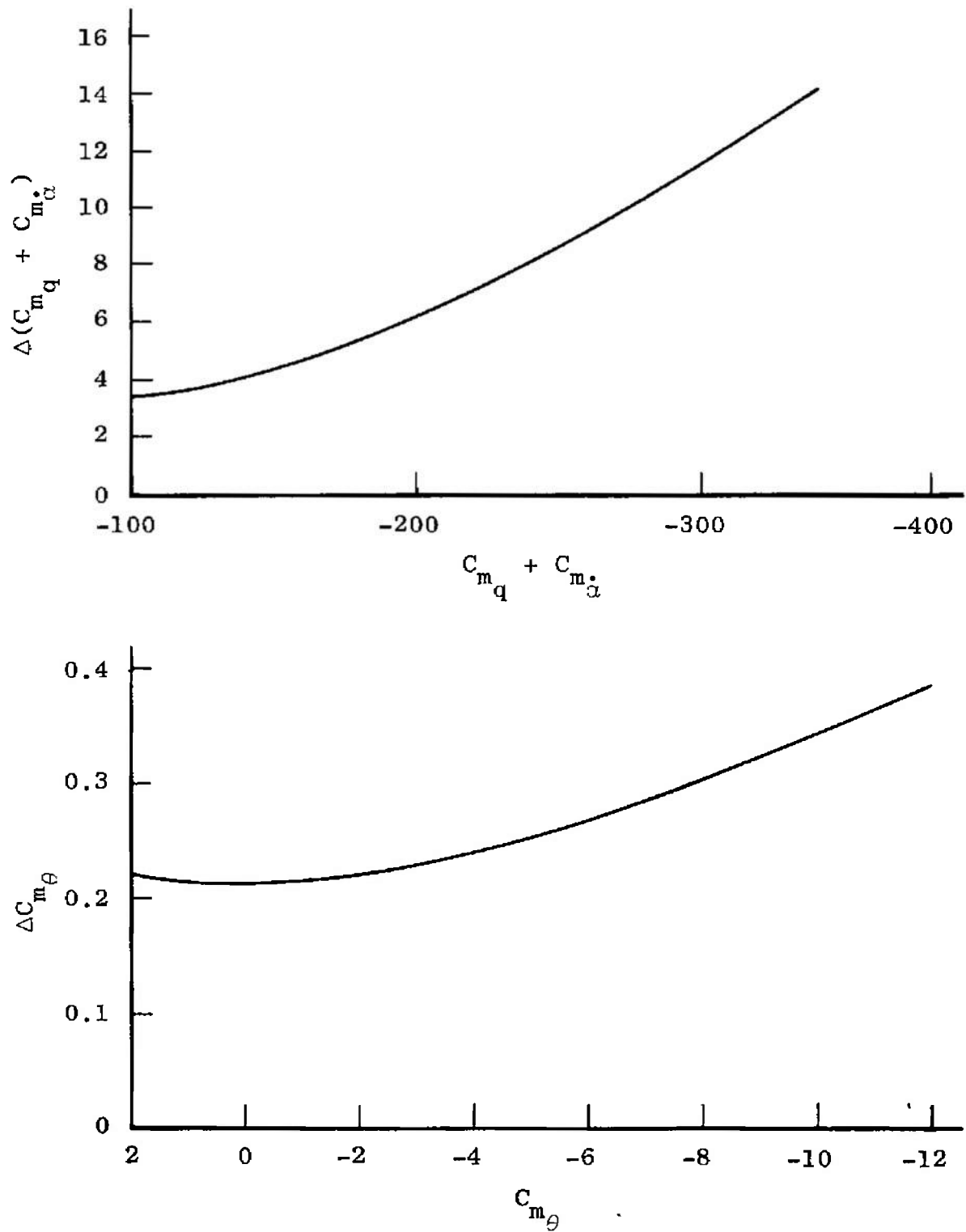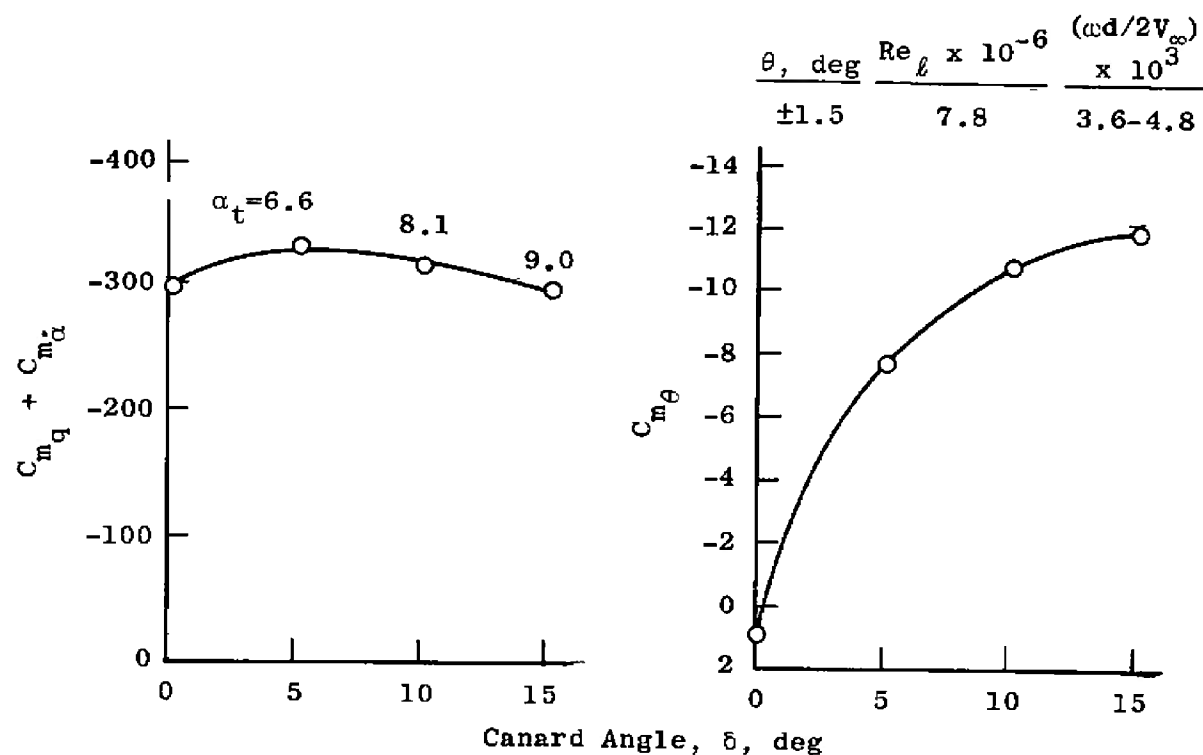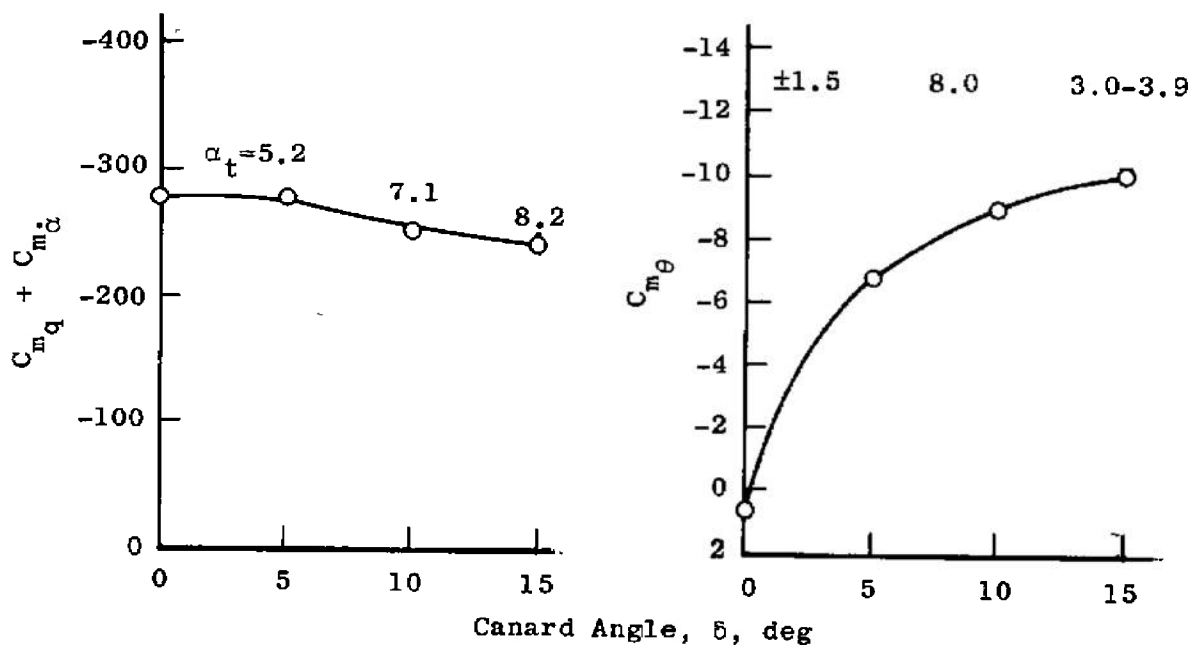Fig. 6 Effect of Canard Angle on the Damping-in-Pitch Derivatives and Effective Slope of the Pitching-Moment Curve
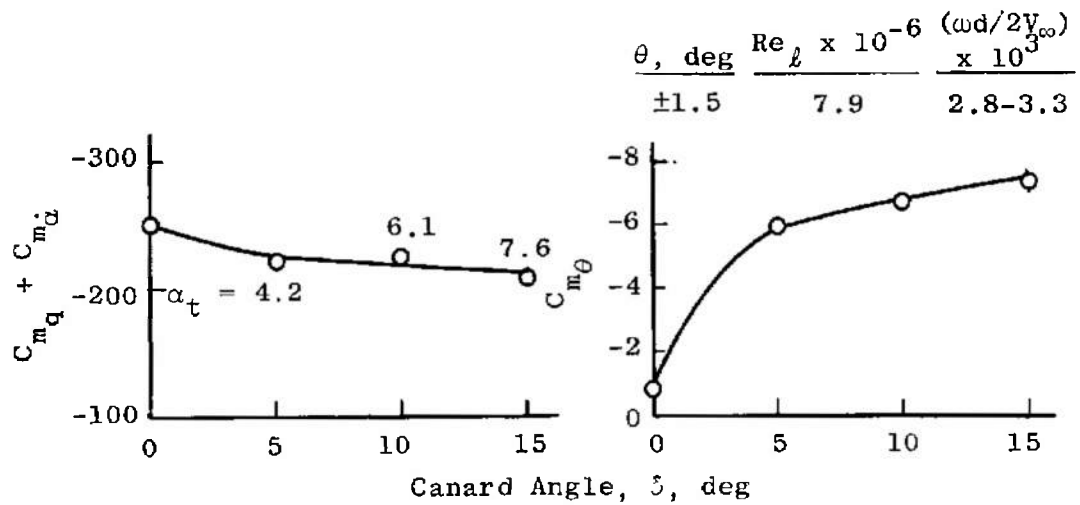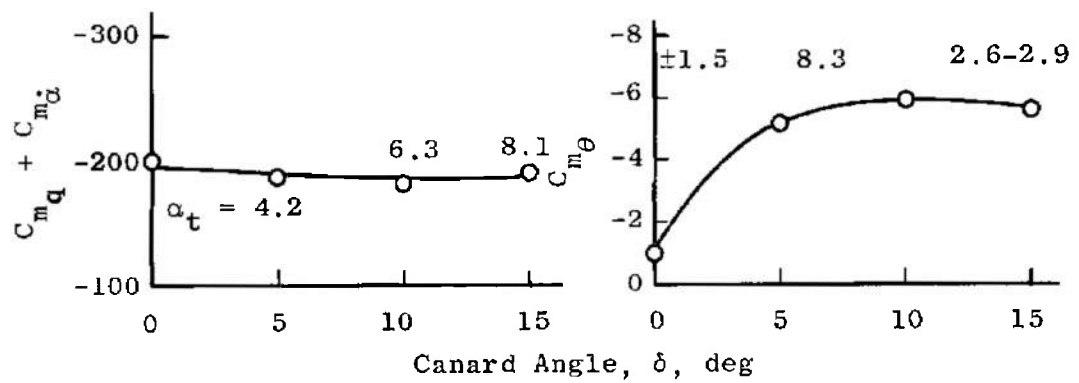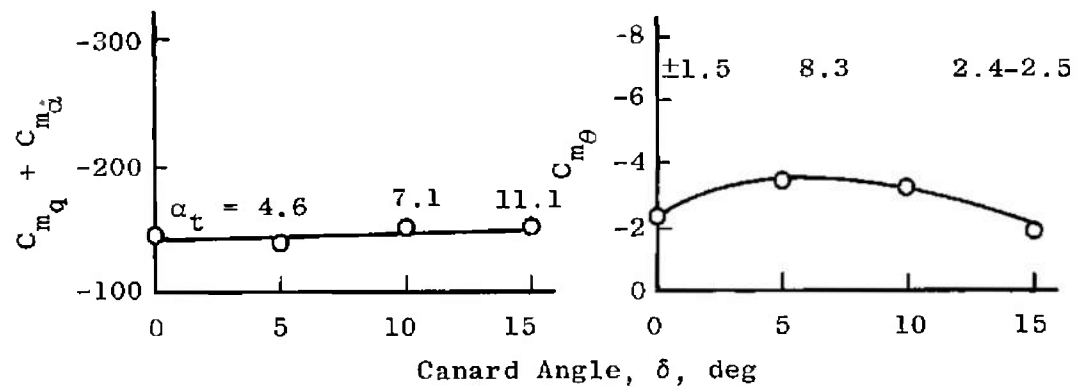
c. $M_\infty = 2.48$

d. $M_\infty = 2.99$
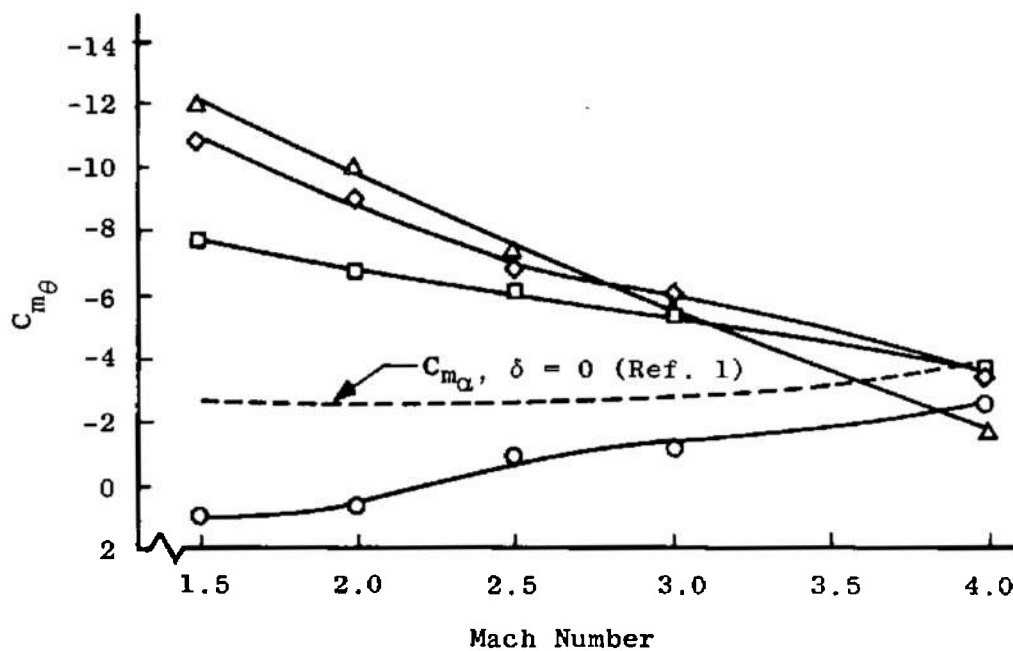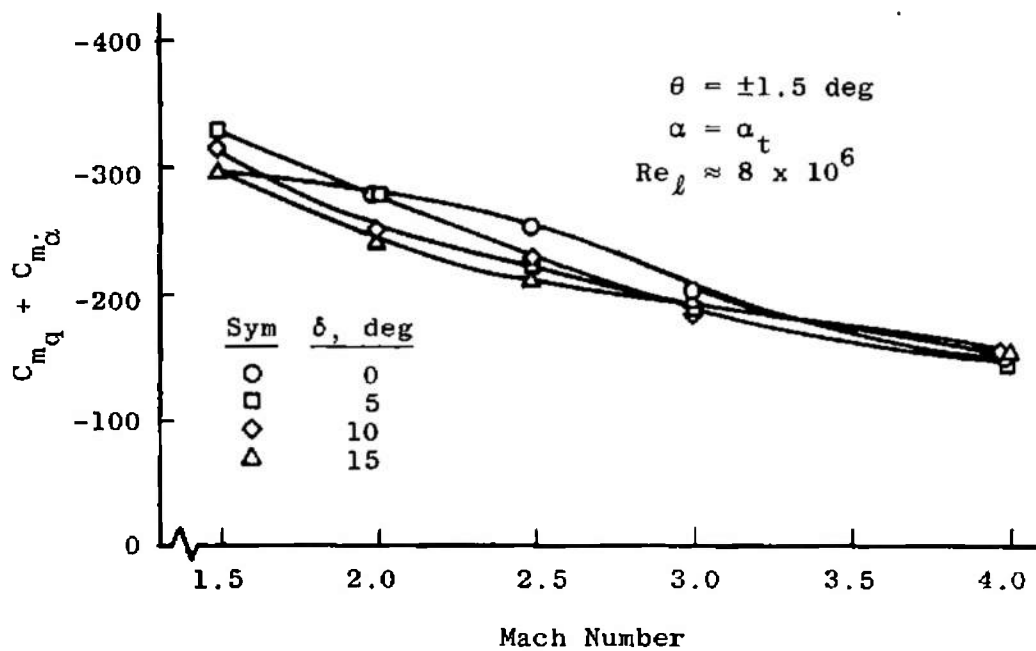

e. $M_\infty = 3.99$

Fig. 6 Concluded

Fig. 7 Effect of Mach Number on the Damping-in-Pitch Derivatives and
Effective Slope of the Pitching-Moment Curve
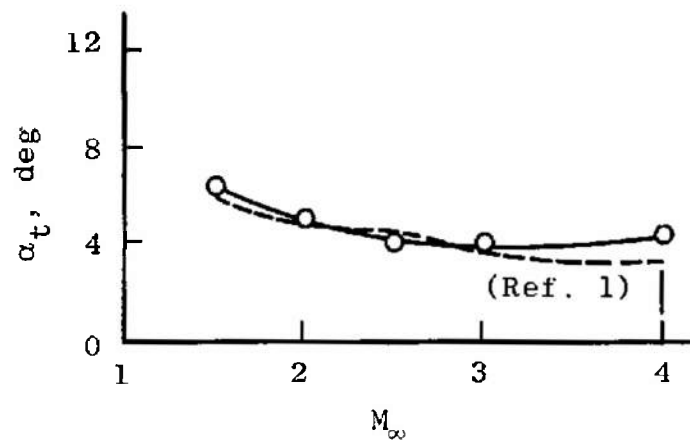
a. $\delta = 5$
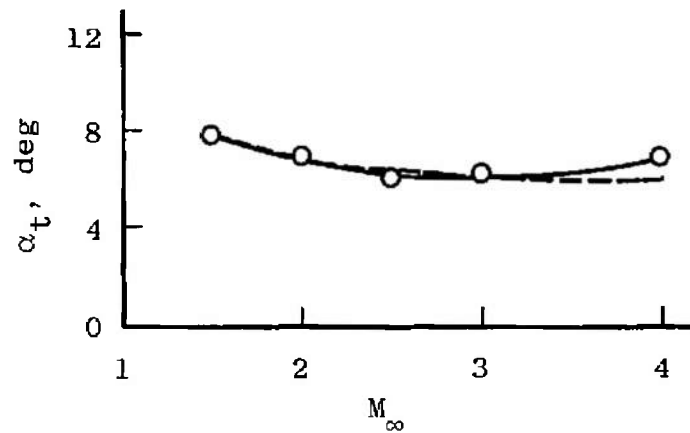
b. $\delta = 10$
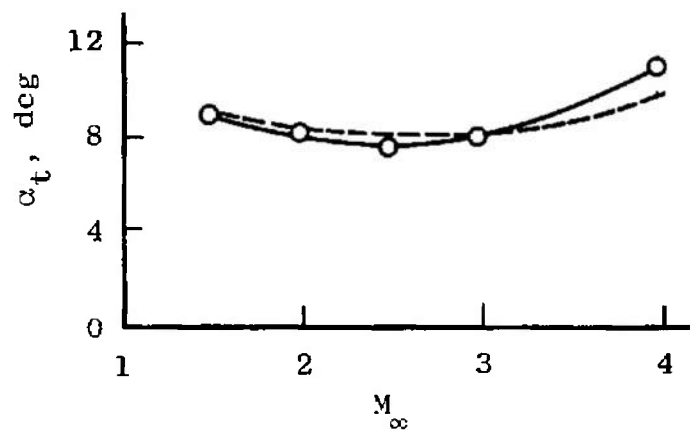
c. $\delta = 15$

Fig. 8 Model Trim Angle versus Mach Number

TABLE I
TEST SUMMARY

δ, deg	M_∞	$Re_\ell \times 10^{-6}$	α, deg[*]		
0	1.49	7.7	-1.9,	0,	2.1
	1.99	8.1	-1.9,	0,	2.1
	2.48	7.9	-1.9,	0,	2.1
	2.99	8.2	-1.9,	0,	2.1
	3.99	8.0	-1.9,	0,	2.1
5	1.49	7.8	5.6,	6.6,	7.6
	1.99	8.0	4.2,	5.2,	6.1
	2.48	7.9	2.1,	4.2,	6.1
	2.99	8.2	2.2,	4.2,	6.1
	3.99	7.8	2.6,	4.6,	6.6
10	1.49	7.8	7.1,	8.1,	9.1
	1.99	8.1	6.1,	7.1,	8.2
	2.48	7.9	5.2,	6.1,	7.1
	2.99	8.3	5.3,	6.3,	7.2
	3.99	8.1	6.1,	7.1,	8.1
15	1.49	7.8	7.9,	9.0,	9.9
	1.99	8.0	7.2,	8.2,	9.2
	2.48	7.9	6.6,	7.6,	8.5
	2.99	8.4	7.1,	8.1,	9.1
	3.99	7.9	10.1,	11.1,	12.0

[*]Note: The trim angle of attack is the middle column.

DOCUMENT CONTROL DATA - R&D

(Security classification of title, body of abstract and indexing annotation must be entered when the overall report is classified)

1 ORIGINATING ACTIVITY (Corporate author)	2a REPORT SECURITY CLASSIFICATION
Arnold Engineering Development Center, ARO, Inc., Operating Contractor, Arnold Air Force Station, Tennessee	UNCLASSIFIED
	2b GROUP N/A

3 REPORT TITLE

DYNAMIC STABILITY TESTS ON A 1/5-SCALE MODEL OF THE BIG Q AIR-TO-AIR MISSILE AT MACH NUMBERS FROM 1.5 TO 4

4 DESCRIPTIVE NOTES *(Type of report and inclusive dates)*

N/A

5 AUTHOR(S) *(Last name, first name, initial)*

Burt, G. E., ARO, Inc.

6 REPORT DATE	7a TOTAL NO OF PAGES	7b NO OF REFS
December 1965	23	3

8a CONTRACT OR GRANT NO. AF40(600)-1200	9a ORIGINATOR'S REPORT NUMBER(S)
b PROJECT NO 5797	AEDC-TR-65-256
c Program Element 62405064	9b OTHER REPORT NO(S) *(Any other numbers that may be assigned this report)*
d Task 579712	N/A

10 AVAILABILITY/LIMITATION NOTICES

~~Release to foreign governments or foreign nationals must have prior approval of AEDC.~~ Qualified requesters may obtain copies of this report from DDC. *Approved for public release; distribution unlimited.*

11 SUPPLEMENTARY NOTES	12 SPONSORING MILITARY ACTIVITY
N/A	Air Force Weapons Laboratory, Air Force Systems Command, Kirtland Air Force Base, New Mexico

13 ABSTRACT

Tests were conducted in the 40-in. supersonic tunnel of the von Kármán Gas Dynamics Facility to determine the dynamic stability characteristics of a 1/5-scale model of the Big Q air-to-air missile. Data were obtained at Mach numbers from 1.49 to 3.99 at the model trim angle of attack and at plus and minus 1 to 2 deg from trim at a near constant Reynolds number of 8×10^6, based on model length. The effects of Mach number and canard angle on the damping-in-pitch derivatives and effective slope of the pitching-moment curve at the trim angle of attack are presented.

DD FORM 1473
1 JAN 64

14 KEY WORDS	LINK A		LINK B		LINK C	
	ROLE	WT	ROLE	WT	ROLE	WT
Big Q						
air-to-air missiles						
1/5-scale model						
supersonic flow						
aerodynamic stability						

INSTRUCTIONS

1. ORIGINATING ACTIVITY: Enter the name and address of the contractor, subcontractor, grantee, Department of Defense activity or other organization *(corporate author)* issuing the report.

2a. REPORT SECURITY CLASSIFICATION: Enter the overall security classification of the report. Indicate whether "Restricted Data" is included. Marking is to be in accordance with appropriate security regulations.

2b. GROUP: Automatic downgrading is specified in DoD Directive 5200.10 and Armed Forces Industrial Manual. Enter the group number. Also, when applicable, show that optional markings have been used for Group 3 and Group 4 as authorized.

3. REPORT TITLE: Enter the complete report title in all capital letters. Titles in all cases should be unclassified. If a meaningful title cannot be selected without classification, show title classification in all capitals in parenthesis immediately following the title.

4. DESCRIPTIVE NOTES: If appropriate, enter the type of report, e.g., interim, progress, summary, annual, or final. Give the inclusive dates when a specific reporting period is covered.

5. AUTHOR(S): Enter the name(s) of author(s) as shown on or in the report. Enter last name, first name, middle initial. If military, show rank and branch of service. The name of the principal author is an absolute minimum requirement.

6. REPORT DATE: Enter the date of the report as day, month, year; or month, year. If more than one date appears on the report, use date of publication.

7a. TOTAL NUMBER OF PAGES: The total page count should follow normal pagination procedures, i.e., enter the number of pages containing information.

7b. NUMBER OF REFERENCES: Enter the total number of references cited in the report.

8a. CONTRACT OR GRANT NUMBER: If appropriate, enter the applicable number of the contract or grant under which the report was written.

8b, 8c, & 8d. PROJECT NUMBER: Enter the appropriate military department identification, such as project number, subproject number, system numbers, task number, etc.

9a. ORIGINATOR'S REPORT NUMBER(S): Enter the official report number by which the document will be identified and controlled by the originating activity. This number must be unique to this report.

9b. OTHER REPORT NUMBER(S): If the report has been assigned any other report numbers *(either by the originator or by the sponsor)*, also enter this number(s).

10. AVAILABILITY/LIMITATION NOTICES: Enter any limitations on further dissemination of the report, other than those imposed by security classification, using standard statements such as:

   (1) "Qualified requesters may obtain copies of this report from DDC."

   (2) "Foreign announcement and dissemination of this report by DDC is not authorized."

   (3) "U. S. Government agencies may obtain copies of this report directly from DDC. Other qualified DDC users shall request through

                                        ."

   (4) "U. S. military agencies may obtain copies of this report directly from DDC. Other qualified users shall request through

                                        ."

   (5) "All distribution of this report is controlled. Qualified DDC users shall request through

                                        ."

If the report has been furnished to the Office of Technical Services, Department of Commerce, for sale to the public, indicate this fact and enter the price, if known.

11. SUPPLEMENTARY NOTES: Use for additional explanatory notes.

12. SPONSORING MILITARY ACTIVITY: Enter the name of the departmental project office or laboratory sponsoring *(paying for)* the research and development. Include address.

13. ABSTRACT: Enter an abstract giving a brief and factual summary of the document indicative of the report, even though it may also appear elsewhere in the body of the technical report. If additional space is required, a continuation sheet shall be attached.

It is highly desirable that the abstract of classified reports be unclassified. Each paragraph of the abstract shall end with an indication of the military security classification of the information in the paragraph, represented as (TS), (S), (C), or (U).

There is no limitation on the length of the abstract. However, the suggested length is from 150 to 225 words.

14. KEY WORDS: Key words are technically meaningful terms or short phrases that characterize a report and may be used as index entries for cataloging the report. Key words must be selected so that no security classification is required. Identifiers, such as equipment model designation, trade name, military project code name, geographic location, may be used as key words but will be followed by an indication of technical context. The assignment of links, rules, and weights is optional.